Optofluidic Technologies

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Abstract: Optofluidics refers to adaptive systems that integrate optical and fluidic devices. Micro and nano-fluidics enable novel devices which introduce liquids into optical structures. We discuss recent optofluidic developments, including optically powered vapor pumps.

Optofluidics, the integration optical and fluidic devices, represents an opportunity to take advantage of the unique properties of liquids to create adaptive systems that can be flexibly reconfigured by redefining the geometry and material properties of optical components via liquid control [1]. Familiar optical components that utilize the properties of fluids include oil immersion lenses, liquid crystals, and dye lasers. However, due to difficulty in fabrication and handling of liquid based optical systems, they have not been fully utilized in the past.

Continuing advances in micro- and nanofabrication are now allowing unprecedented control of liquid systems. Fluids can currently be metered and transported accurately at size scales on the order of the wavelength of

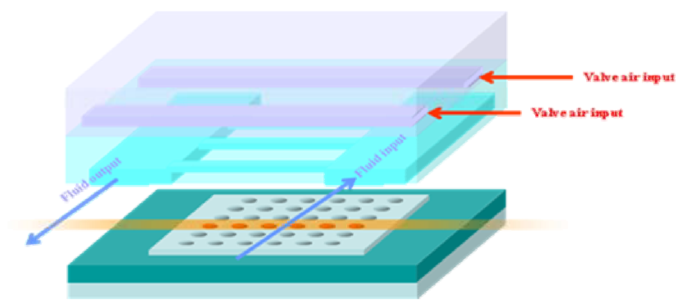

Figure 1: A schematic drawing of an optofluidic system. Fluidic control lines are bonded on top of a photonic band gap structure, allowing definition of an optical waveguide by altering the refractive index of a single line of holes.

visible light [2]. This enables solid and liquid elements to be combined to create adaptive photonic devices (see figure 1). Optofluidics allows the fabrication of novel optical components that are necessary for lab-on-chip biophotonic systems. Our research has produced examples of light sources and detectors that are not only miniaturized and integrated, but also have functional advantages over their non-optofluidic relatives. The Bragg feedback dye laser designed and produced by Li et al. allows for continuous tuning of the laser wavelength via modification of the composition of the dye solution [3]. High resolution microscopy can be performed using the optofluidic microscope, in which fluid is used to scan a biological sample very close to array of submicron aperture s [4]. This scanning microscope could enable massively parallel studies of micro-organisms over long timescales. Another simple biological optofluidic circuit, developed by Choi et al. is a bacteria detector which uses electro-orientation to measure the presence of viable bacteria in urine by selective scattering of polarized light [5].

One of the advantages of optofluidics is the ability to use fluidics to provide well controlled sample delivery in a liquid environment. A particular research interest of our group is using light beams using to actuate fluids, allowing optofluidic devices that not only use fluids to provide optical functionality, but also use optics as a control system. Recently, Liu et al. have demonstrated the actuation of a liquid in a microchannel using a scanning focused laser beam [6]. We have extended this technique to realize optically powered pumping by photothermal absorption [7].

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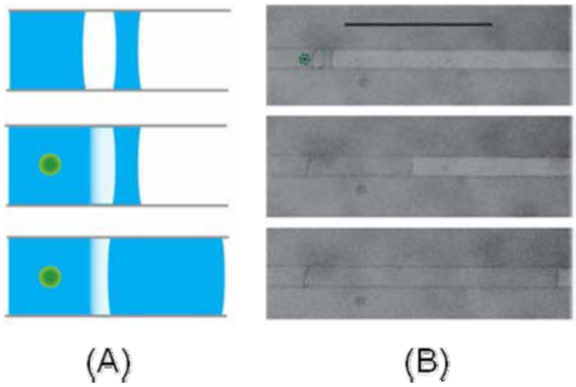

Figure 2: (A) Schematic diagram of laser driven vapor pumping. (B) Photographs of vapor pump in operation. The scale bar is 100 microns. The pumping rate is approximately 2 microns/sec in a 30 micron by 5 micron channel.

Gold nanoparticles that are resonant around 530 nm are deposited into a microchannel using block-copolymer lithography [8]. By introducing a pinned air bubble into a liquid filled region in the channel, we create pumping action using a stationary, focused laser spot. The laser heats the substrate very close to the air-liquid interface causing increased evaporation on the 'warm side', of the air bubble (figure 2). The vapor recondenses on the cool side, causing continuous mass flow across the air bubble. The vapor based pump is able to transport liquid very simply, without the need for a scanning beam or complicated modulation. In addition, these optically driven evaporative techniques may be useful for integrated microscale chemical processes requiring phase transition, such as distillation and evaporative concentration.

Optofluidics allows for a large range of adaptive optical circuits, by leveraging the physical properties of liquids and the ability to design and construct devices with features on the scale of the optical wavelength. We have discussed examples of optofluidic systems that can enable integrated biological studies. In addition, optical control of fluidic behavior represents an emerging technique that can allow for 'closed loop' systems where sample delivery is controlled optically. We acknowledge the support of the DARPA Center for Optofluidic Integration, and the DARPA CAD-QT program.

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